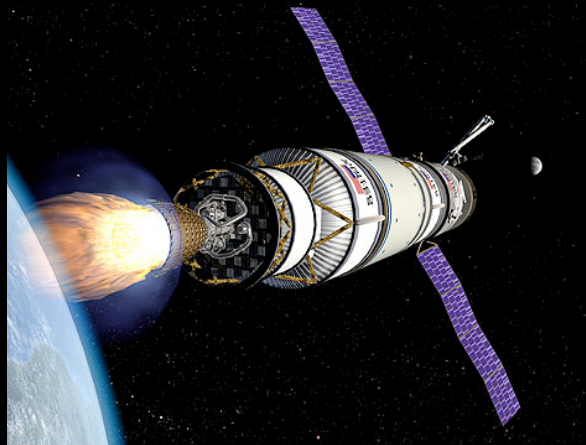
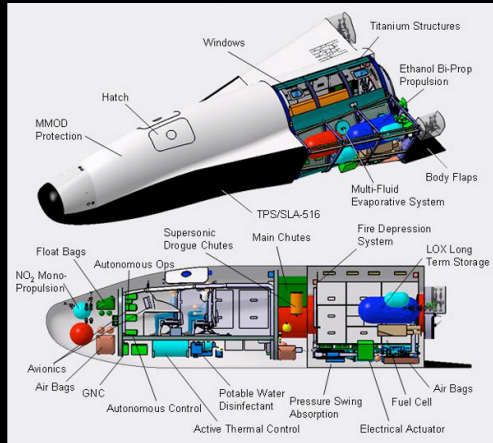


TPS In-Flight Health Monitoring Project Progress Report



Chris Kostyk, Lance Richards, Larry Hudson
NASA Dryden Flight Research Center
Edwards, CA



William Prosser
NASA Langley Research Center
Hampton, VA

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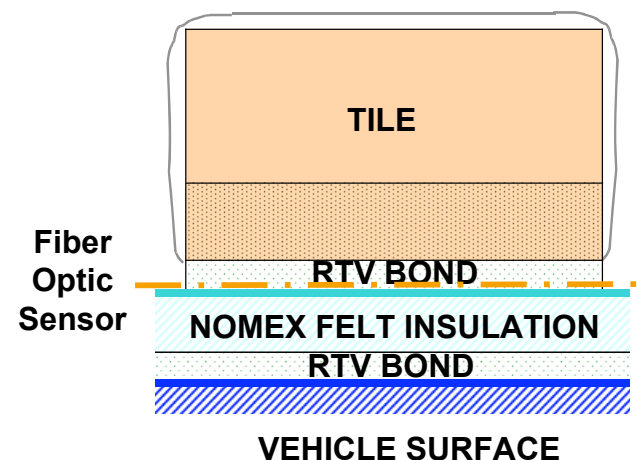
Outline

- Project Background, Goals, Approach
- Accomplishments
 - Testing Approach
 - Sensor / System Testing & Development
 - Thermal Analysis
- Conclusions / Current Efforts



Background

- Space vehicles utilize TPS to mitigate severity of re-entry heating
- TPS health monitoring is a necessary advancement for safety of flight
- New Approach – embed lightweight, sensitive, fiber optic strain and temperature sensors within the TPS
 - Temp / strain monitoring
 - Damage detection



Background

- Fiber Bragg Grating (FBG) sensors can be highly multiplexed using with LaRC demodulation architecture
- Hundreds of FBG sensors can be placed at variable intervals along the length of fiber
- FBG sensors max service temperature approximately 600°F
- FBG system currently limited to 4-5 sps (\approx 10 sps by summer 2006)
 - Acceptable for temperature / strain monitoring
 - Real-time damage detection (long term goal)



Goals

- Develop and demonstrate prototype TPS health monitoring system
- Develop a thermal-based damage detection algorithm
- Characterize limits of sensor / system performance
 - Determine fiber sensitivity and accuracy beneath tiles
 - Characterize the transient thermal response differences between damaged and undamaged TPS
 - Determine optimal fiber placement
 - Determine required sensor density
- Develop a methodology transferable to new designs of TPS health monitoring systems



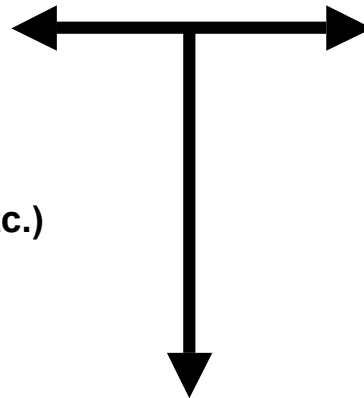
Project Approach

Perform Setup / System Tests

- Discern significant physics present in test setup
- Validate model
- Determine sensor / system limits (response, accuracy, etc.)

Validate Tests with Thermal Analysis

- Utilize MSC's Patran Thermal and generate computational model
- Determine physics
- Potential algorithm development application



Generate transient thermal response characteristics database for algorithm development and implementation

Develop algorithm for use with system

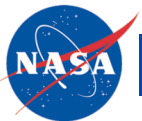
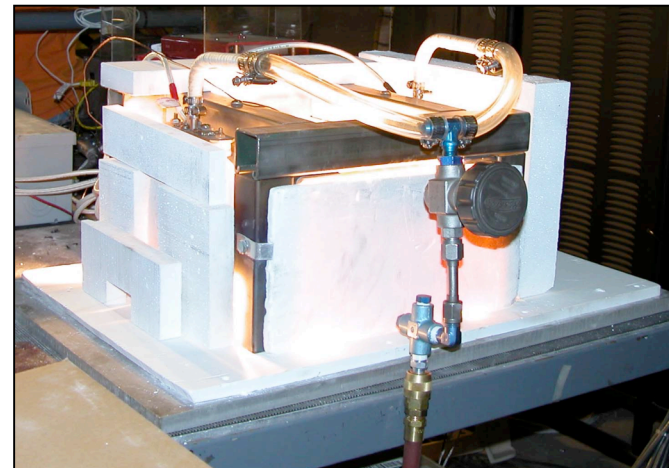
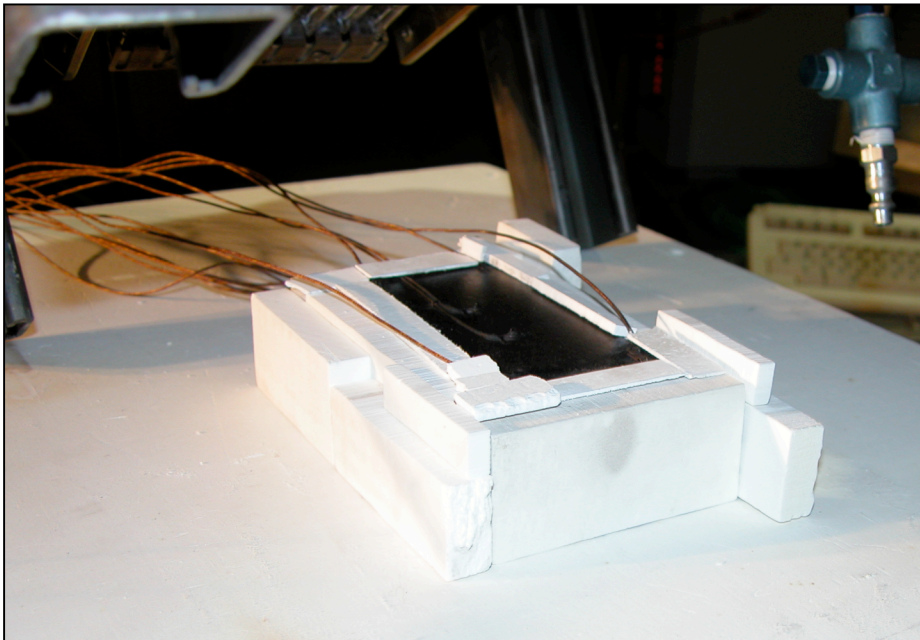
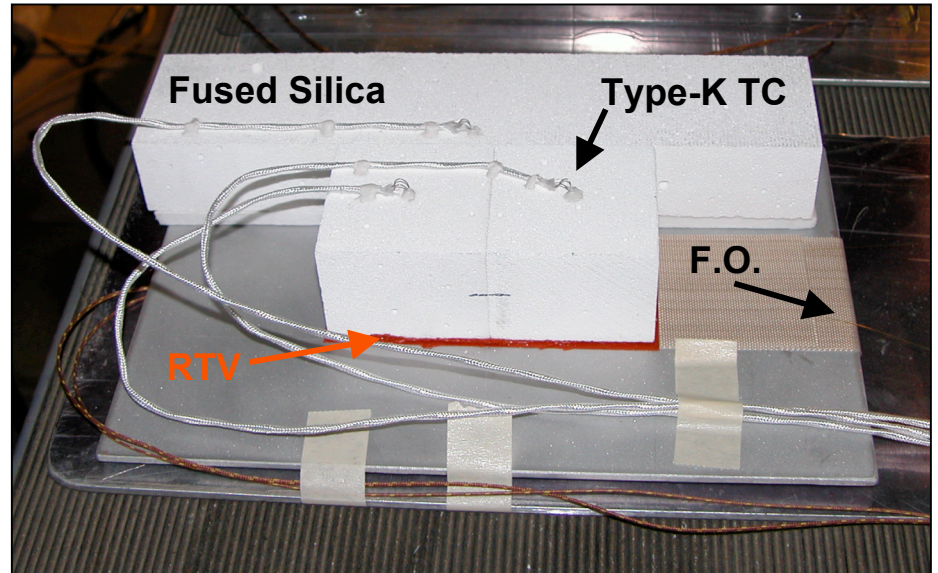
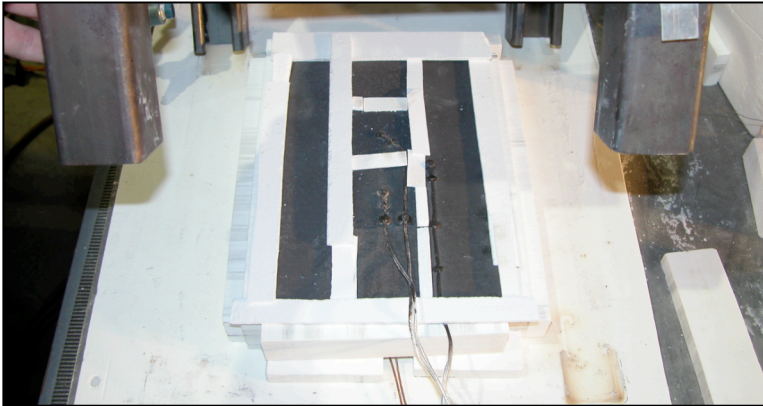


Testing Approach

System Component	Feature(s) Tested	Physics / Relevance
Test Article	Test article material	Material property data uncertainty
	Test article design	Uniformity/direction of heat transfer modes
	Exterior insulation	Uniformity/direction of heat transfer modes
	Interior insulation	Uniformity/direction of heat transfer modes
	Emissivity/Transmissivity coatings	Uniformity/direction of heat transfer modes
Test Setup	Supports	Undesired conduction
	Profile input method	Surface temperature/rate precision
	Thermal control	Control authority and precision across different test articles
	Data acquisition system	TC data veracity
	Heating element	Uniformity & spectral properties of lamp/test article
FBG Sensor System	FBG Sensor System	Verify optimal placement of FBG in bondline

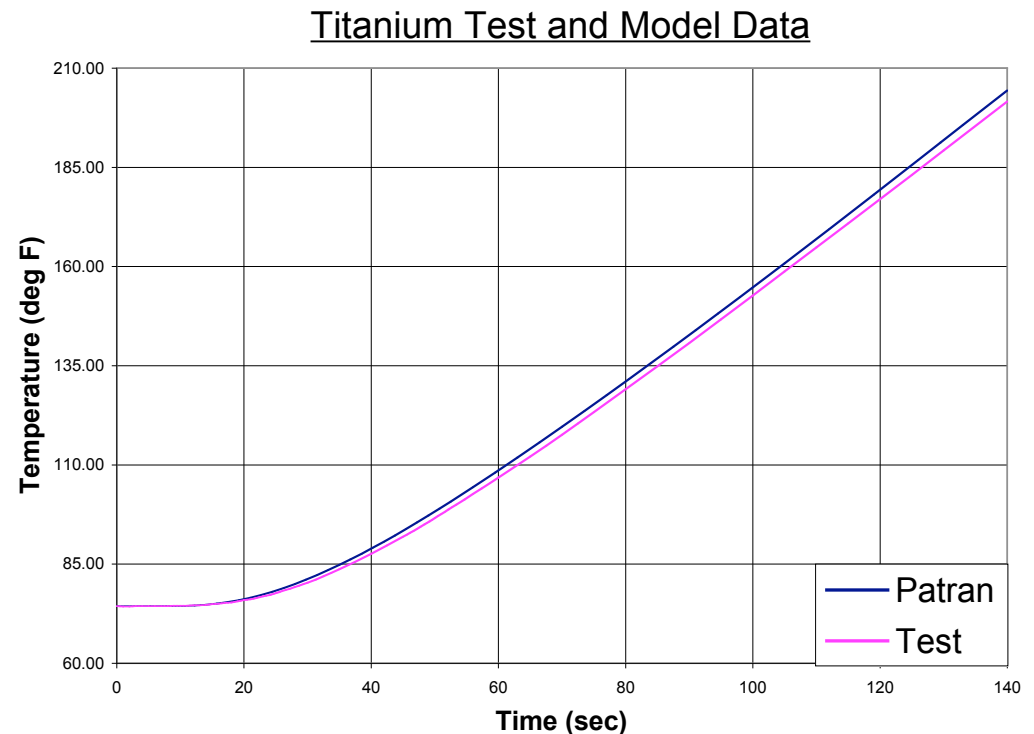


Setup/System Testing



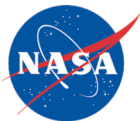
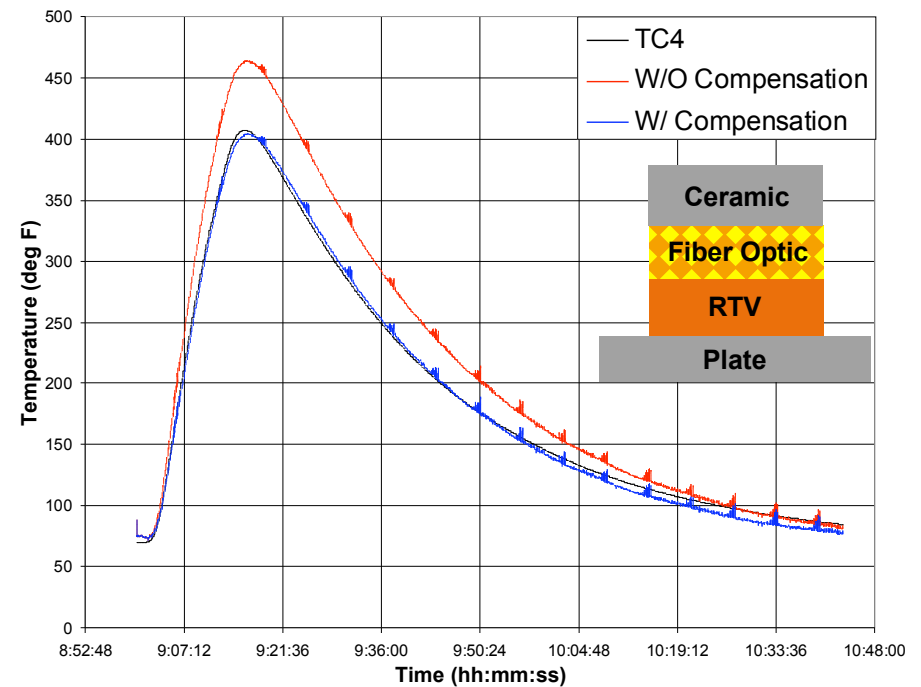
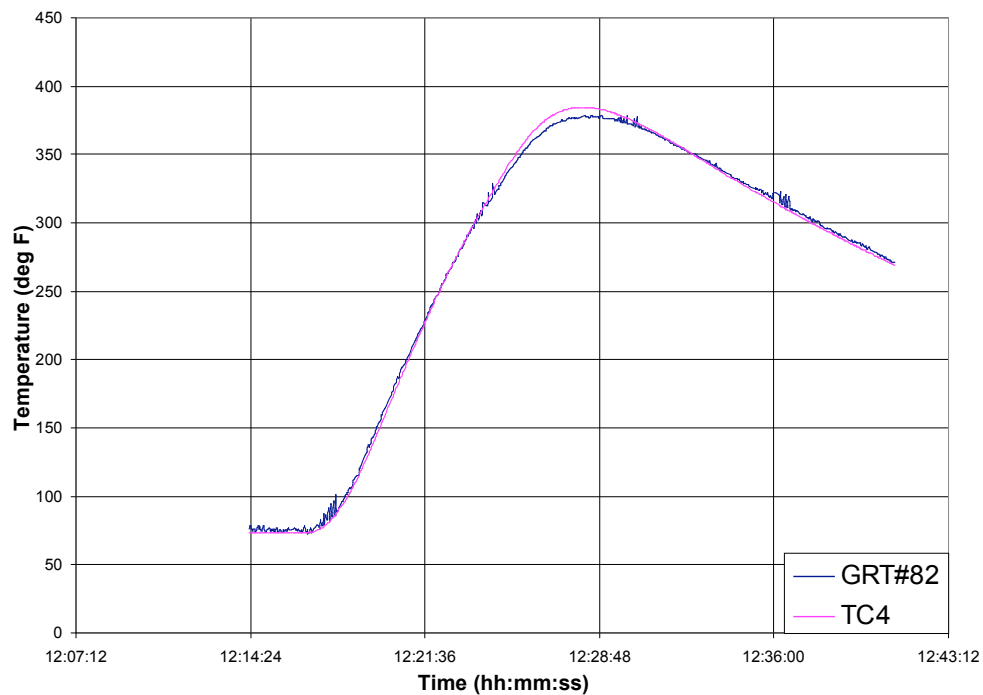
Setup / System Testing

- Experimented with setup for improved model comparison (48 tests)
 - Test article insulation
 - Gap insulation, seam covers
 - Conduction paths (supports, wires, etc.)
 - Profile input, repeatability
 - Data acquisition system
 - Monolith vs. Compartmentalized articles
 - Titanium vs. Ceramic
 - Test article cover
 - Test article coatings
 - IR Camera, & Quartz vs. GRHT
 - Alumina Oxide & Shuttle Tile



Setup / System Testing

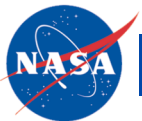
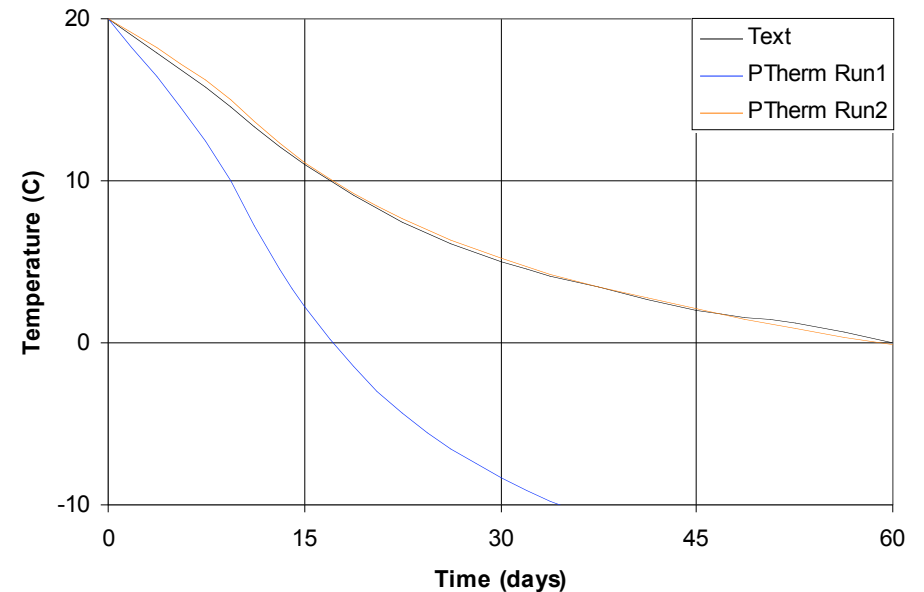
- Validated FBG for use as TC when bonded with RTV to bottom surface of ceramic
- Validated FBG for use as TC when bonded with RTV between ceramic and Al substrate
 - Successful compensation of strain transfer from Al substrate through RTV layer



Thermal Analysis

- Videos → Tutorials → Textbook Solution Comparison
- Validated by LTA & SPAR codes
- Model system, refine
 - Simplify to monolith, add materials
 - Try simple, known materials
 - Perform mat. prop. perturbation study
 - Investigate mat. prop. thermal variation effects
 - Examine B.C. effects
 - Create performance envelope (10K, 0.1Cp, etc.)
 - Study solution convergence/quality
 - **mesh refinement**
 - **FD vs. FEM**
 - **1D/2D/3D models**
 - Simulate possible additional physics

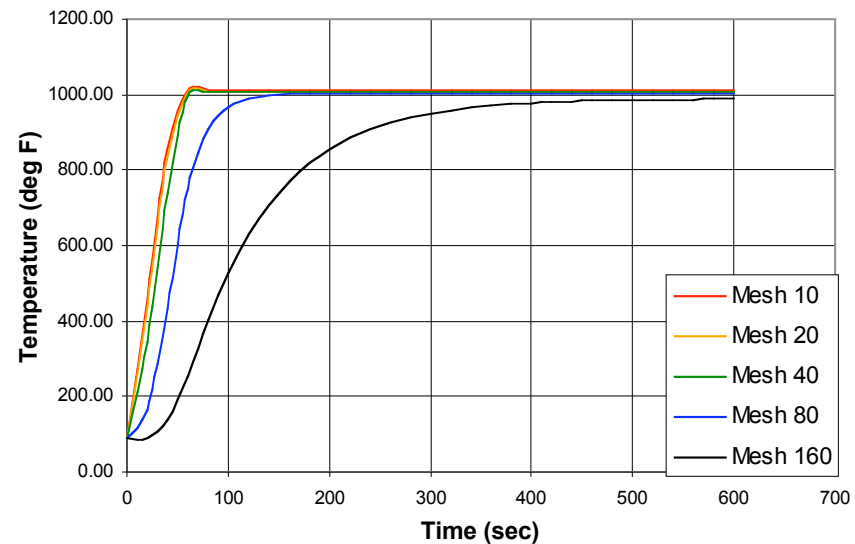
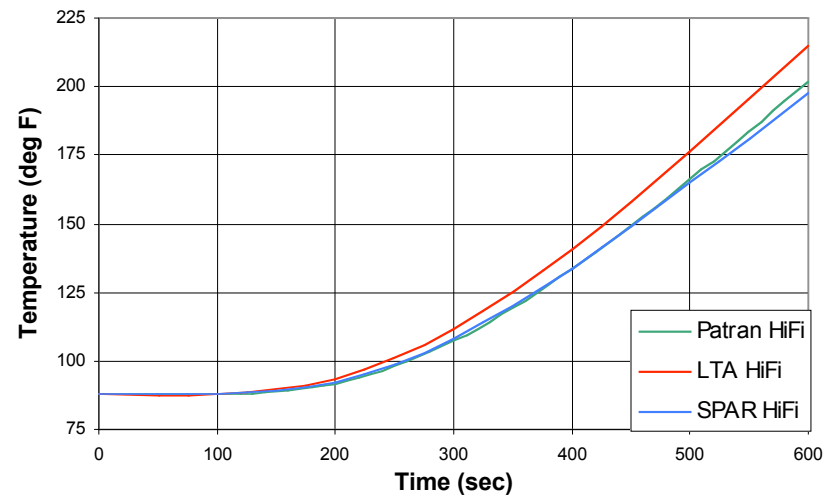
Patran vs. Textbook Solution



Thermal Analysis

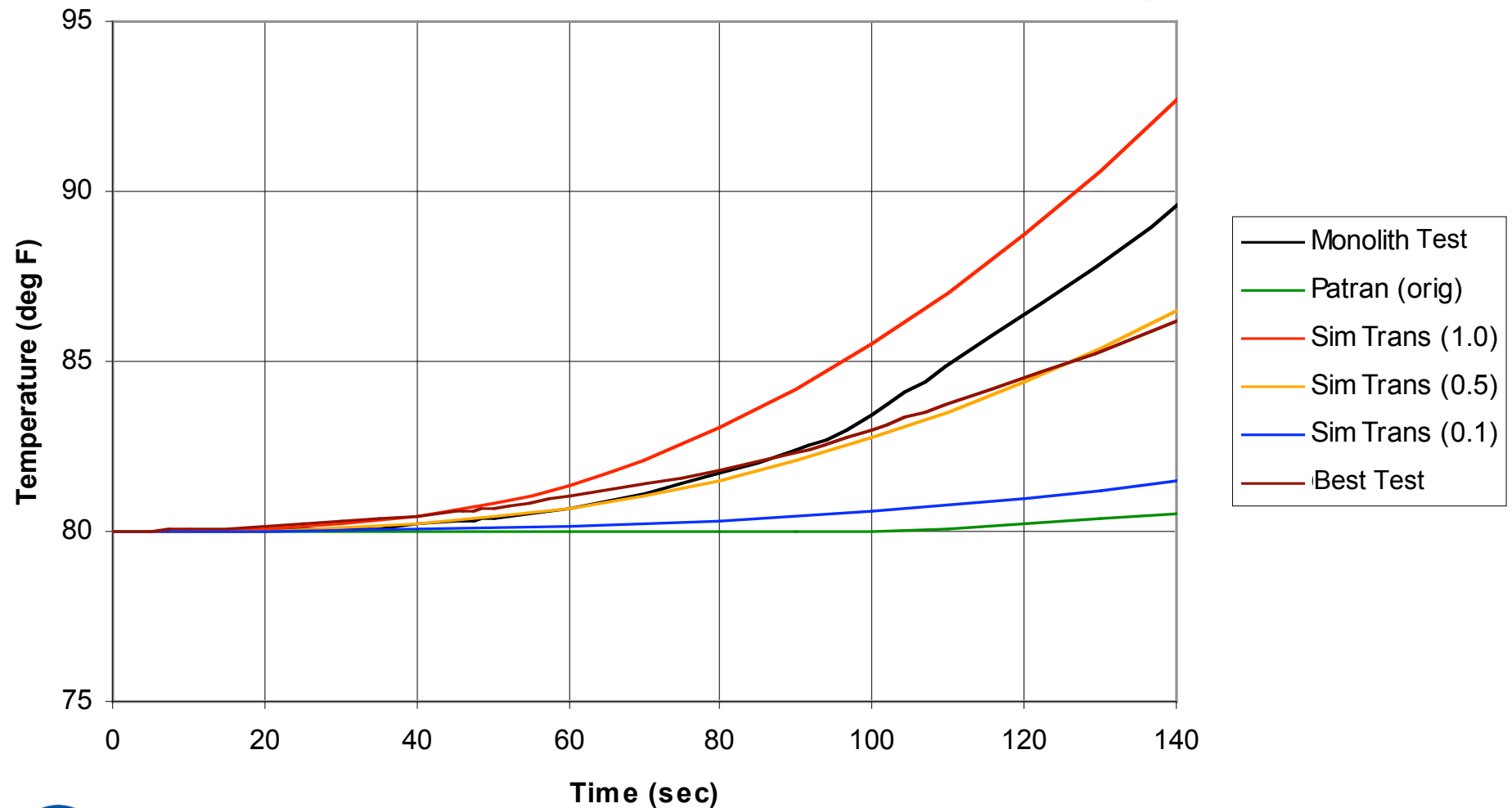
Outcomes of Patran modeling effort:

- 65 Patran models
- Identified underlying physics in test materials and established confidence in test setup
- Successfully calibrated computational and experimental results
- Revealed bugs in Patran Thermal
 - FD does not work for transient (probably others)
 - Inability to run a 1D analysis with an LBC on the end of a bar element



Thermal Analysis Results

Comparison of Best Test/Model Results and Simulated Transmissivity Models



Conclusions & Current Efforts

- Established confidence in understanding of both test setup and model
- Validated system / sensor performance in simple TPS structure
- Completed initial system testing, ready to begin algorithm development effort to complete prototype
- Generating damaged thermal response characteristics database from tests with varying levels of fidelity
- Developing test plan for integration testing of proven FBG sensors in simple TPS structure with proven AE sensors on NASA / CSIRO's Concept Demonstrator
- Developing partnerships to apply technology



Questions?

